Analysis and suppression of reflections in far-field antenna measurement ranges

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***Abstract*— This paper presents the analysis of the reflections in two kind of spherical far field ranges: one if the classical acquisition where the AUT is rotated and the second one corresponds to the systems where the AUT is fixed and the antenna probe is rotated. In large far field systems this is not possible, but this can be used to the measurement of small antennas, for instance, with the SATIMO StarGate system. In both cases, it is assumed that only one frequency is acquired and the results should be improved cut by cut, in order not to lose the advantages or far field measurements. Finally, some practical results are studied using measurements of one antenna in the outdoor far field facility of LIT INPE in Brazil.**

I. INTRODUCTION

Two methods to reduce the unwanted reflection effects in far field antenna measurements are presented: the first method is a modification of the of the technique explained in [1] for planar and cylindrical near field antenna measurements. The proposed method can be applied to measurements where the AUT is fixed (at least in one axis of rotation) and the antenna probe is moved. This is not the normal case for outdoor system, but it can be applied to the multiprobe StarGate SATIMO systems and Arc Systems. For outdoor systems, or even classical indoor spherical anechoic systems with a poor reflectivity level, this method cannot be applied. However, this paper analysis the problem of the reflections, and a second method to suppress them is presented. Simulations are presented to check the validity of both techniques.

Finally, some tests have been done in the in the facilities of Antenna Lab from LIT INPE in Brazil, in order to extract some conclusions.

II. SPATIAL FILTERING TECHNIQUE FOR MULTIPROBE MEASUREMENTS

This first method is based on spatial filtering over the plane where the antenna under test (AUT) is placed. To calculate the field in this plane a diagnostic technique is employed. However, in contrast to error source identification, the reconstructed field has to be obtained in a zone larger than the antenna dimensions. Thus, it is possible to identify virtual sources out of the antenna aperture, which appear due to the presence of reflections (image theory). Then, by cancelling the virtual and unwanted sources, the related reflected components can be suppressed. Finally, by employing this filtered reconstructed field, a new radiation pattern is calculated.

A. Reflection Suppression Method

If reflected waves are present in antenna measurements, the radiation properties obtained will be perturbed. These same incorrect results are achieved with an equivalent system where reflections can be viewed as direct waves coming from virtual sources (see Fig. 1). Such a replacement is explained in detail via image theory [2], which was also used in [3] to study ground reflections as image current distributions. The identification of the virtual sources is not possible with a conventional diagnostic technique, where the field is only reconstructed over the antenna aperture. However, if the field reconstruction is performed over a surface larger than the antenna dimensions, the aforementioned fictitious sources can be found and cancelled with a filtering process. Thus, the basis of the proposed method is a modified diagnostic technique that provides the reconstructed field in a region whose size in each direction depends on the distance between the AUT and the possible reflective surfaces, which is at least twice as large as that distance, to ensure the correct image identification. In the case of the integral equation method, equivalent currents have to be calculated at a greater number of points. Thus, the number of unknown quantities in the system of integral equations increases; therefore, more time is required to solve the system. On the other hand, modal expansion methods are based on the fast Fourier transform of the PWS, and as a result, the spatial domain, in which the reconstructed field is calculated, and the spectral domain are related as follows:

$$\text{(spectral domain) } k_x = -\frac{\Delta k_x \cdot M_x}{2}, \cdots, \frac{\Delta k_x \cdot M_x}{2}; step = \Delta k_x$$
$$\downarrow$$
$$\text{(spatial domain) } x = -\frac{\pi}{\Delta k_x}, \cdots, \frac{\pi}{\Delta k_x}; step = \frac{2\pi}{\Delta k_x \cdot M_x} \quad (1)$$

$$\text{(spectral domain) } k_y = -\frac{\Delta k_y \cdot M_y}{2}, \cdots, \frac{\Delta k_y \cdot M_y}{2}; step = \Delta k_y$$
$$\downarrow$$
$$\text{(spatial domain) } y = -\frac{\pi}{\Delta k_y}, \cdots, \frac{\pi}{\Delta k_y}; step = \frac{2\pi}{\Delta k_y \cdot M_y} \quad (2)$$

where Δk_x and Δk_y are the spectral steps and M_x and M_y represent the total number of samples in each spectral direction, k_x or k_y, respectively. With these relationships, a straightforward procedure to obtain the reconstructed field over a larger surface is to reduce the spectral step sizes, thus increasing the spatial lengths because these parameters are inversely proportional, as deduced from (1) and (2).

B. Application to SATIMO Stargate system

Fig. 2 shows an example of a SATIMO Stargate system. In this situation, the antenna under test rotates in azimuth and the set of probes take the field in elevation. For each circular acquisition the AUT is fixed and a source reconstruction on each circular acquisition can be performed.

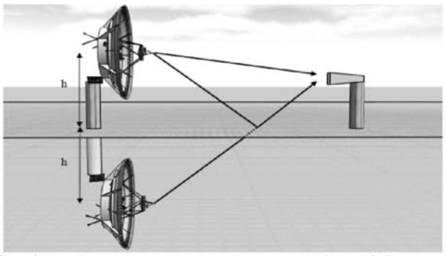

Fig. 1. Reflections in antenna measurements viewed by means of image theory.

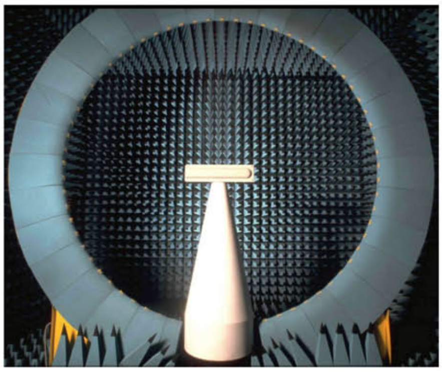

Fig. 2. SATIMO StarGate System

Some simulations with a 9x4 array antenna at 9 GHz (with non-separable excitation) have been performed. In this case, a scatterer with reflection coefficient is equal to -2 is introduced in the horizontal plane, at a distance of 1.5 meters. The antenna probes are in a radius of 6 meters, in order to achieve far field distance. Fig.3 shows the source reconstructions of two orthogonal cuts, assuming that the scatterer is placed in the horizontal plane. As it can be observed, the reflections can be detected and suppressed in the x direction, performing a spatial filtering. In the y direction, these reflections cannot be detected, since they are superposed with the sources coming from the AUT in that plane. Fortunately, the effect of the reflection is higher in the plane of the reflection. Therefore, good improvement is obtained. Fig. 4 and Fig. 5 show the radiation pattern in both planes, from -90 to 90 degrees. In the horizontal plane the filtered radiation pattern is very accurate, cancelling perfectly the reflections, while in the vertical plane the improvement is not complete, although the ripple is cancelled.

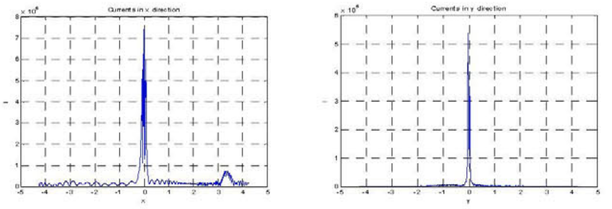

Fig. 3. Source reconstruction in the line of the reflection and in the line normal to the reflection.

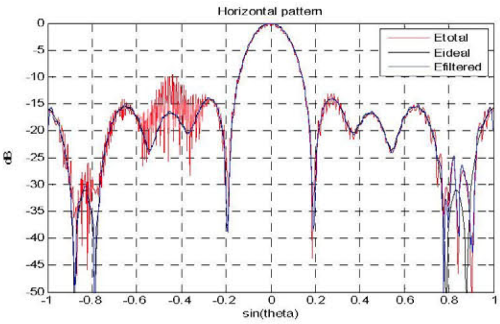

Fig. 4. Ideal, corrupted and filtered radiation patterns for horizontal plane.

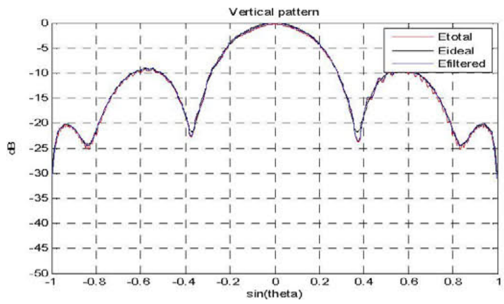

Fig. 5. Ideal, corrupted and filtered radiation patterns for vertical plane.

III. Reflection Suppression in Classical Far Field Ranges

In the case of the classical far field ranges the AUT is moving continuously. Therefore, the reflection cannot been considered as the image of the AUT for each individual cut, as it was considered before, or in a general case for a planar near field acquisition. However, when an acquisition is performed, the measured far field can be considered as the sum of a direct pattern and a reflected pattern coming from a different angular direction (Fig. 7) for a case where the antenna probe is located at 80 meters and the reflection is at 30 meters.

In this situation, if a source reconstruction technique is applied, the AUT and the reflection cannot be directly separated (Fig. 7). However, the result of this source reconstruction is the vectorial sum (Fig. 8) of the sources coming from the direct ray and the sources coming from the reflected ray. These last ones have a phase slope equivalent to the maximum of the reflected pattern in Fig. 6.

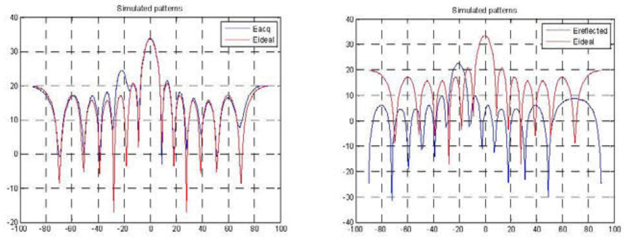

Fig. 6. Simulated pattern and individual direct and reflected pattern.

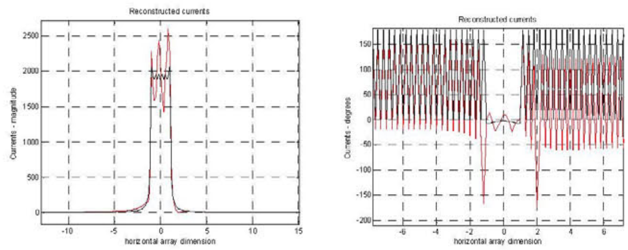

Fig. 7. Ideal and corrupted sources (amplitude and phase)

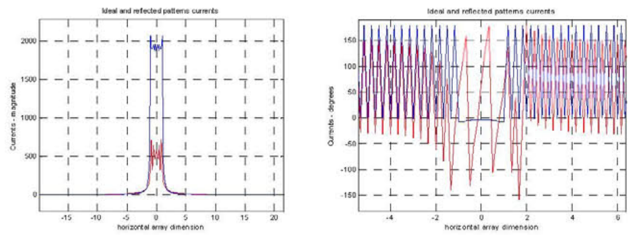

Fig. 8. Sources coming from the direct and from the reflected ray (amplitude and phase).

With one measurement is not possible to extract the ideal measurements, but, if a flip-test is performed, the ideal measurement can be easily process, since the direct currents remain the same, while the reflected currents are the complex conjugate of the first measurement (3). Once the flip-test is performed, the ideal currents can be calculated using (4), where the angle θ of the reflected ray should be known. This can be easily known geometrically, or looking for the maximum of the subtraction of the normal pattern and the flip-test pattern. Fig. 9 shows the results in the application of eq. (4) to the simulated acquisition, and Fig. 10 shows the reconstructed radiation pattern.

$$I_{total} = I_{direct} + I_{reflected} \approx I_{direct} \cdot \left[1 + \rho \cdot e^{j\left(D_{direct} - D_{reflected}\right)} \cdot e^{jk_o x_i \sin(\theta_{ref})}\right] \quad (3)$$

$$I_{reconst} \approx I_{direct} \approx 0.5 \cdot \left[I_{acq} + I_{flip} + \frac{j\left(I_{acq} - I_{flip}\right)}{\tan\left(k_o x_i \sin\theta_{ref}\right)} \right] \tag{4}$$

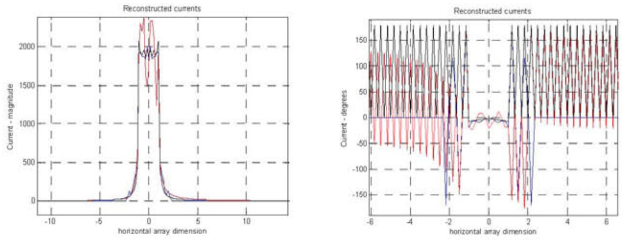

Fig. 9. Corrupted, ideal and reconstructed currents (amplitude and phase).

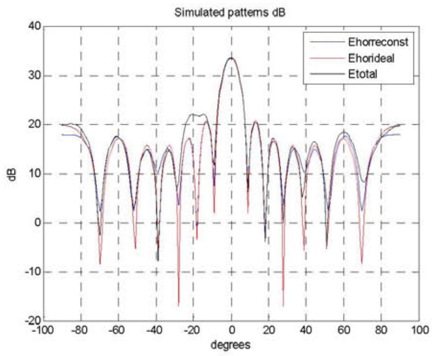

Fig. 10. Corrupted, ideal and reconstructed radiation pattern

IV. Application To LIT-INPE Facilities

Spatial filtering is being applied to LIT-INPE Facilities in Brazil. Fig. 11 shows the far field antenna measurement system, where the side trees create an important reflection.

Fig. 11. LIT INPE far field facility

Until now, a regular far field has been measured, and a source reconstruction technique has been applied. Results reported in Fig. 13 show that improvement in the radiation pattern has been obtained since the ripple, even in the main lobe, has been suppressed. In a future, a flip-test will be performed in order to validate with measurements the second technique.

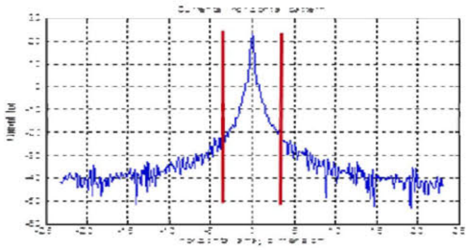

Fig. 12. Reconstructed currents and filtered zone.

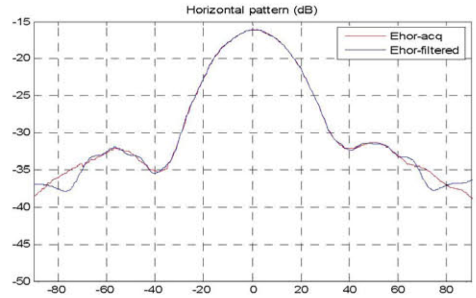

Fig. 13. Measured and filtered pattern.

V. Conclusions

Spatial filtering has been applied to the reduction of reflections in far field measurements. Two cases have been studied: the first one is the case of the SATIMO multiprobe systems, where the AUT remains fixed during one cut, while the second one is the classical far field antenna measurement. In the first case, the reflections can be easily suppressed, at least in one plane, applying a spatial filtering. In the second case, the reflections cannot be suppressed with only one cut, but if a flip-test is applied (doubling the acquisition time), the reflections can be cancelled. This can be applied to reflections in one side wall, but they could be extended to reflections in the ground.

Acknowledgment

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References

[1] F. J. Cano-Fácila, S. Burgos, F. Martín, M. Sierra-Castañer, "New Reflection Suppression Method in Antenna Measurement Systems Based on Diagnostic Techniques" IEEE Trans. On Antennas & Propagation, Vol. 59, No. 3, March 2011, pp. 941-949

[2] C. A. Balanis, "Electromagnetic theorems and principles," in *Advanced engineering electromagnetic*, Ed. New York: Wiley, 1989, ch. 7, sec. 4, pp. 314-323.

[3] R. J. Lytle, "Ground reflection effects upon radiated and received signals as viewed via image theory," *IEEE Trans. Antennas Propagat.*, vol. AP-20, No. 6, pp. 736-741, Nov., 1972.